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Technical Memorandum No. 33-52
(Addendum B)

Some Interrelationships and Long-Range Implications of the C-3 Lunar Rendezvous and Solid Nova Vehicle Concepts

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October 2, 1961

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(NASA-CR-136549) SOME INTERRELATIONSHIPS AND LONG RANGE IMPLICATIONS OF C-3 LUNAR RENDEZVOUS AND SOLID NOVA VEHICLE CONCEPTS (Jet Propulsion Lab.) 12 p

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
(NASA CONTRACT NO. NASw-6)

(JPL-TM-
Technical Memorandum No. 33-52, add. B)
(Addendum B)

Some Interrelationships and Long-Range Implications of the C-3 Lunar Rendezvous and Solid Nova Vehicle Concepts (C××)

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I. INTRODUCTION

Technical Memorandum No. 33-52 presented two approaches, one indirect and one direct, for placing man on the Moon. The former capitalized on the *Saturn* C-3 vehicle capability when coupled with a lunar surface rendezvous and lunar vehicle assembly technique. This approach has the advantage of fitting into and growing out of the existing unmanned lunar program. By assembling on the lunar surface in a relatively strong gravitational field, it would avoid much of the docking problem of Earth orbit rendezvous and simplify component orientation and translational motions during assembly. Unlike the orbit rendezvous a checkout of the lunar assembly procedures here on Earth would be entirely practical. Finally, it would permit assembly, remote checkout, and testing of the return vehicle before a man is ever committed to the mission.

In a separate study the Memorandum also examined an all-solid-propellant *Nova* injection vehicle in the 25-30 million-pound-weight class with the capability of placing a man on the Moon and returning him without the need for any assembly after Earth launch. This direct approach would capitalize on (a) the country's ability to scale up rapidly to very-large-sized solid vehicles (Ref. 1) and (b) the demonstrated reliability of clustered solid motors, e.g., the 15 motors for the 3 high-speed stages of RTV and *Explorer* (see Ref. 2). It would mate this capability with a program philosophy that is most applicable to early vehicle development and conservative design with no advancements in the state-of-the-art other than size scaling, to provide us with what appears to be a unique opportunity to leapfrog the vehicle capability of the Russians; the limited solid propellant technology of the Russians would prohibit duplication.

Although the two concepts discussed in the Memorandum originated as two independent aspects of the manned lunar mission, it has become increasingly evident that there are some interesting interrelationships when examined in the context of NASA's broad, long-range planning. *Because this Addendum, of necessity, contains areas of conjecture and judgment rather than technical facts exclusively, it was deliberately separated from the Technical Memorandum itself.*

Section II of this Addendum presents a skeleton plan for a part of NASA's manned lunar and manned planetary program. It shows that, by using both the indirect and direct approaches in a parallel effort, we could derive the highest assurance of placing a man on the Moon and returning him safely at the earliest possible date. This parallel effort would, however, involve a minimum of duplication because *Nova* and *Saturn* vehicle capabilities, as well as the rendezvous technique, will be needed by NASA in subsequent programs. Out of these two vehicle efforts would quickly come the much larger vehicle capability required for the next manned lunar milestone. Subsequently, by judicious development and application of nuclear or electric propulsion, the basic vehicle capability, with a minimum of redesign, would again be significantly uprated for later lunar and, possibly, early manned planetary missions.

Section III explains some of the reasons for arriving at the particular plan, and Section IV mentions some of its disadvantages, several significant advantages, and some interesting implications.

II. AN APPROACH TO NASA'S MANNED SPACE PROGRAM

For the purposes of this examination it will be assumed that NASA's short and long-term objectives for the nation's manned space program will consist essentially of:

1. A manned lunar landing about 1966-7 as its immediate and most urgent objective.
2. A manned lunar laboratory or lunar base about 1969; its support will require the transport of large quantities of supplies and equipment. Depending on circumstances this base could lead to a relatively large scientific laboratory or industrial complex; cargo-ferrying operations at relatively low unit cost would be a necessary characteristic.
3. A manned landing and return about 1975-77, from Mars or Venus (probably Mars). This, in turn, might lead to a manned base on the planet. Even in the initial Mars landing, cost would be of overriding importance because of the sheer magnitude of the planetary task.

Figure 1 shows the assumed major milestones and indicates schematically how the two concepts of Technical Memorandum No. 33-52 provide (1) a parallel, independent, and quick approach for the lunar landing mission and (2) early and relatively inexpensive follow-on capability for subsequent NASA manned space missions. Figure 2 expands somewhat on details and growth of the launch vehicle family. It is interesting to note the relatively small number of engine modules that constitute the propulsion family.

The vehicle capabilities indicated in Fig. 1 would grow out of:

1. The basic 4-step all-solid *Nova* vehicle described in TM 33-52,
2. The liquid *Saturn* C-3 which is assumed to have a first step consisting of two F-1 engines, a second step of four J-2 Lox-H$_2$ engines, and a third step of six LR 115-Lox-H$_2$ engines and,
3. A spacecraft powered by an electric propulsion system of approximately 20-40 megawatts. Electric propulsion is used here to represent an advanced propulsion system. Time and further study may indicate a nuclear system is more desirable.

The number beneath each vehicle is its approximate launch weight, and the number immediately above indicates the payload capability in Earth orbit of the first two *Saturn* or first three *Nova* stages. The number beneath each major milestone or mission is the weight that can be landed on the lunar, or Martian, surface by one vehicle of the type just to its left, i.e., by the vehicle planned for that mission.

A. The Manned Lunar Landing

Figure 1 shows that a parallel approach, the liquid-propelled *Saturn* C-3 using a lunar surface rendezvous and the all-solid *Nova*, would be adopted for the 1966 milestone in order to enhance the likelihood at an early date of returning one to three men from the Moon. This dual approach would have several advantages:

1. Completely independent approaches would be used; the mission rather than some specific vehicle would have a back-up. Thus if the rendezvous technique of the C-3 approach were to encounter lunar assembly or other difficulties, the direct ascent technique of the *Nova* should avoid those difficulties. Alternately, if development problems in our liquid hydrogen technology, clustered J-2's or liquid F-1 engines were to produce delays in the C-3 schedule, the solid-rocket technology should avoid a duplication of those problems. On the other hand, if the large scale-up in size in the solid *Nova* program resulted in a delay, the much smaller C-3 is less apt to encounter the problem. The mission would still be accomplished if either vehicle development, by itself, were delayed or unsuccessful.
2. The basic technology required for each spacecraft system could be identical except that the C-3 system would require the development of the unmanned lunar surface rendezvous-assembly technique. Hence, failure in one approach at a crucial point in our program could be aided by the existence of the other. For example:
   a) If the C-3 were to become man-rated first, but difficulties were encountered in lunar assembly, the solid *Nova* (non-man-rated) could be used to place a completely assembled spacecraft on the lunar surface; the man-rated C-3 could then transport the man to the Moon for prompt return.
   b) If the solid *Nova* were to become man-rated first, were to land a manned spacecraft on the Moon, but encountered minor or semi-major difficulties in the system (damaged landing gear,

black-box problem, etc.), two unmanned C-3's could be standing by on Earth for emergency launch to furnish necessary supplies and repair equipment to the men in the *Nova*.

3. If the C-3 were to encounter a fundamental barrier in its development, components from the solid *Nova* program could be adapted as a solid-propellant back-up vehicle for the C-3. For example the upper 3 steps of the solid *Nova* are capable of putting approximately 270,000 lb in Earth orbit and, with a storable-liquid-propellant fourth step, approximately 70,000 lb to escape. Alternately a fundamental barrier for the solid *Nova* would delay a *Nova* vehicle program only until the F-1 and J-2 engines from the liquid C-3 program could be adapted to a *Nova* vehicle.

B. The Lunar Laboratory or Base

Shortly after completing the 1966 mission, by either vehicle approach (see Fig. 1), the solid *Nova* would begin delivering 20,000-35,000 lb cargoes to the lunar surface for construction of the lunar laboratory or base. As quickly as schedules and the level of reliability would permit, the *Nova's* payload capacity would be upgraded to about 110,000 lb (delivered on the lunar surface) by substituting, for the two upper solid-propellant steps, LOX-H_2 J-2 stages (12 J-2's for step 3 and 4 J-2's for step 4) from the *Saturn* C-3 program. The Earth-orbit capability of the first three stages of this combined solid and liquid propellant or "Hybrid *Nova*" vehicle would be approximately 930,000 lb. To be able to orbit approximately one million pounds by 1968-69 might well constitute a "spectacular feat" of considerable propaganda value within itself.

The technique developed by the C-3 for rendezvous on the lunar surface in 1966 would be used throughout this 1966-69 period because solid or Hybrid *Nova's* must rendezvous cargoes on the lunar surface at the site of the lunar laboratory.

C. The Lunar Industrial Complex

About 1969, as the 930,000-lb electric spacecraft with its greater payload fraction and lower unit cost became available, it would be substituted for the conventional spacecraft and become a cargo ferry between Earth orbit and lunar orbit. Cargo weights delivered to the lunar surface per vehicle would then approach 215,000 to 440,000 lb. In order to minimize the solar radiation hazard, the transport of men to and from the Moon would probably be performed with the all-chemical vehicle because of its much shorter transit time (about 2½ days vs 35 to 160 days for the indicated electric spacecraft payloads). The electric propulsion system itself can be made available on the indicated schedule but only if a substantial increase in the over-all electric propulsion effort is effected very soon.

The use of electric spacecraft for the lunar industrial complex and later the Mars landing (or alternately an Earth-orbiting Laboratory), will necessitate the development of the more difficult rendezvous technique,[1] rendezvous in orbit. The C-3 vehicle following the 1966 manned lunar landing could be oriented toward development of such a rendezvous technique; its capability would permit man to be an important part of the operations. The C-3 would also be needed for unmanned trips to Mars and/or Venus in preparing for the manned planetary landing in 1975 (see Fig. 1). Thus the C-3 vehicle does not become a dead-end development when the 1966 manned lunar mission becomes an accomplished fact. Of course much of the technology developed in the C-3 program continues to be utilized indefinitely in the upper stages of the Hybrid *Nova* and its programs.

D. Manned Mars Missions

From about 1969 on, the Hybrid *Nova* with its electric spacecraft would continue to be used for the lunar industrial complex as a relatively low cost ferry and to build up vehicle reliability, operational lifetime, and experience to become the workhorse vehicle for lunar missions. As the reliability of the electric spacecraft increased for longer operating periods, it would be used in the planetary program for the unmanned Mars landing and return about 1971-73 and the manned Mars landing and return about 1975-77.

No attempt has been made to present a formal manned planetary program. By noting the severe requirements that planetary missions place on vehicle and spacecraft propulsion, however, one quickly learns that serious attention must be given to the "big booster and spacecraft requirements" for the manned Mars landing even at this early date. Table 1 shows some relatively crude performance estimates for Mars circumnavigation and orbiter missions for vehicles based on Lox-H_2 chemical propulsion and a 3-man mission.

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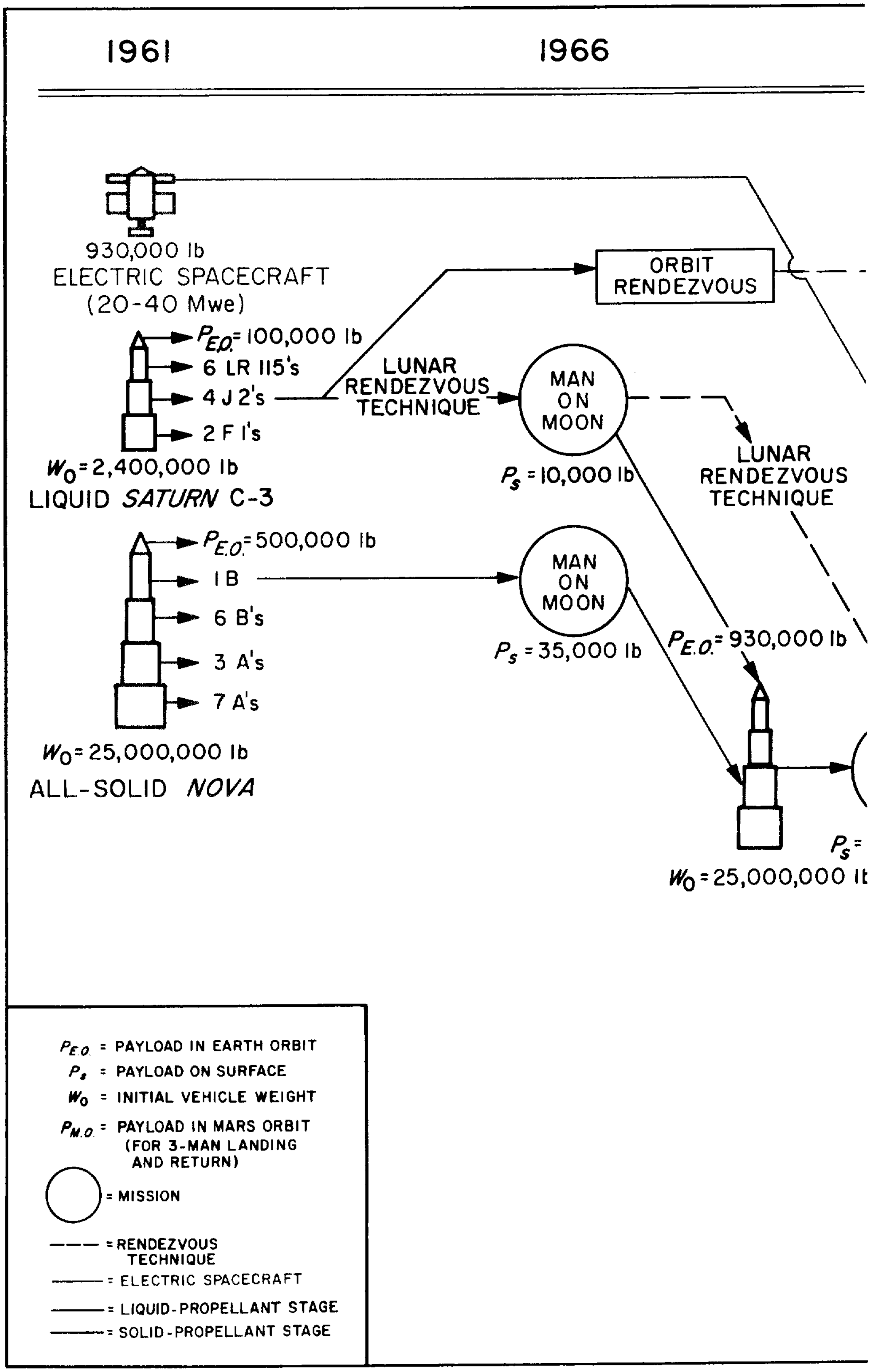
[1]It seems desirable also to developed the orbital rendezvous technique if nuclear propulsion is used in the spacecraft.


1961
1966
930,000 lb
ELECTRIC SPACECRAFT
(20-40 Mwe)
ORBIT RENDEZVOUS
$P_{E.O.}$ = 100,000 lb
6 LR 115's
4 J 2's
2 F 1's
LUNAR RENDEZVOUS TECHNIQUE
MAN ON MOON
W_0 = 2,400,000 lb
LIQUID *SATURN* C-3
P_s = 10,000 lb
LUNAR RENDEZVOUS TECHNIQUE
$P_{E.O.}$ = 500,000 lb
1 B
6 B's
3 A's
7 A's
MAN ON MOON
P_s = 35,000 lb
$P_{E.O.}$ = 930,000 lb
W_0 = 25,000,000 lb
ALL-SOLID *NOVA*
P_s =
W_0 = 25,000,000 lt
$P_{E.O.}$ = PAYLOAD IN EARTH ORBIT
P_s = PAYLOAD ON SURFACE
W_0 = INITIAL VEHICLE WEIGHT
$P_{M.O.}$ = PAYLOAD IN MARS ORBIT (FOR 3-MAN LANDING AND RETURN)
= MISSION
= RENDEZVOUS TECHNIQUE
= ELECTRIC SPACECRAFT
= LIQUID-PROPELLANT STAGE
= SOLID-PROPELLANT STAGE

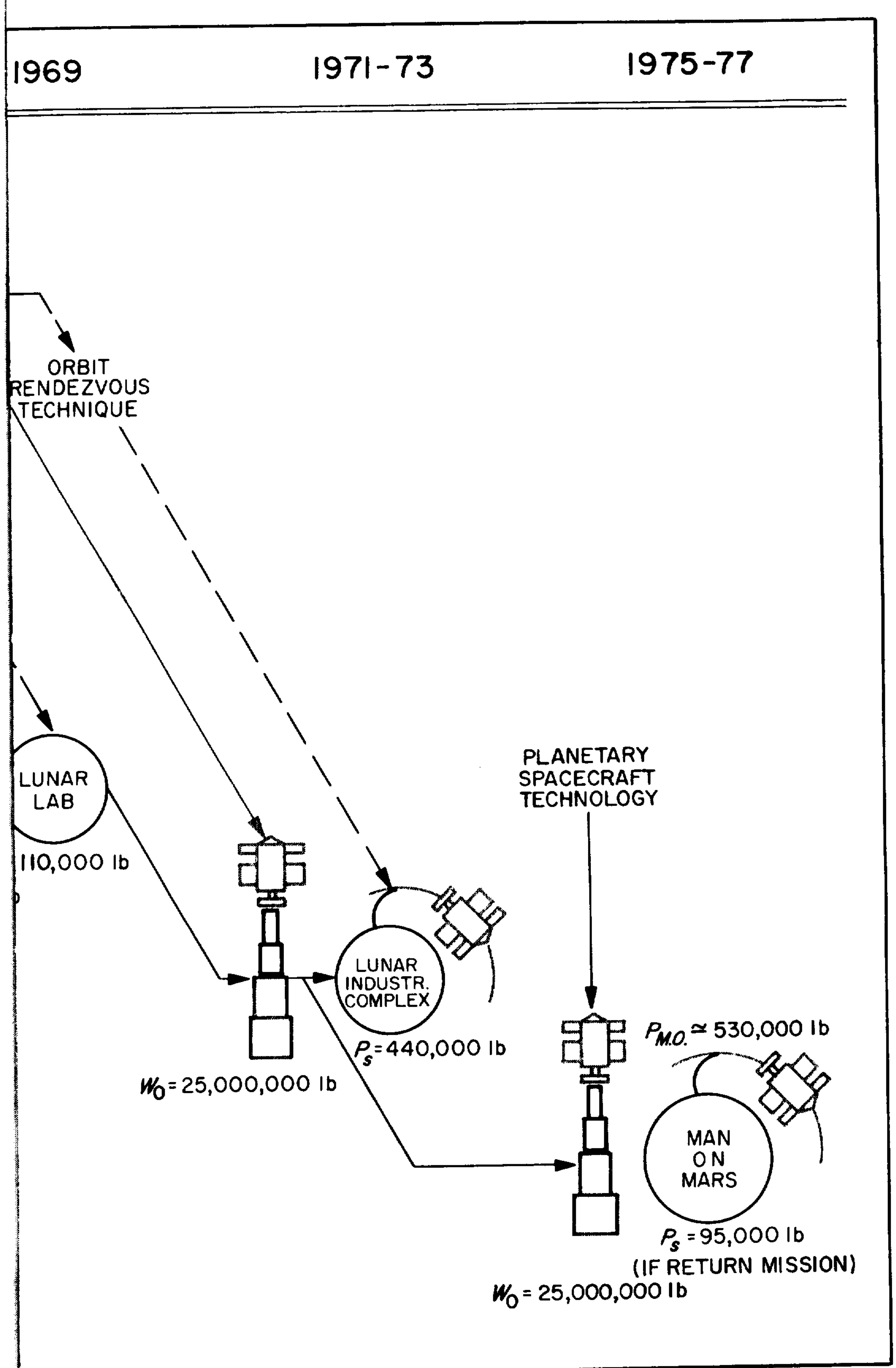


Fig. 1. Manned space program

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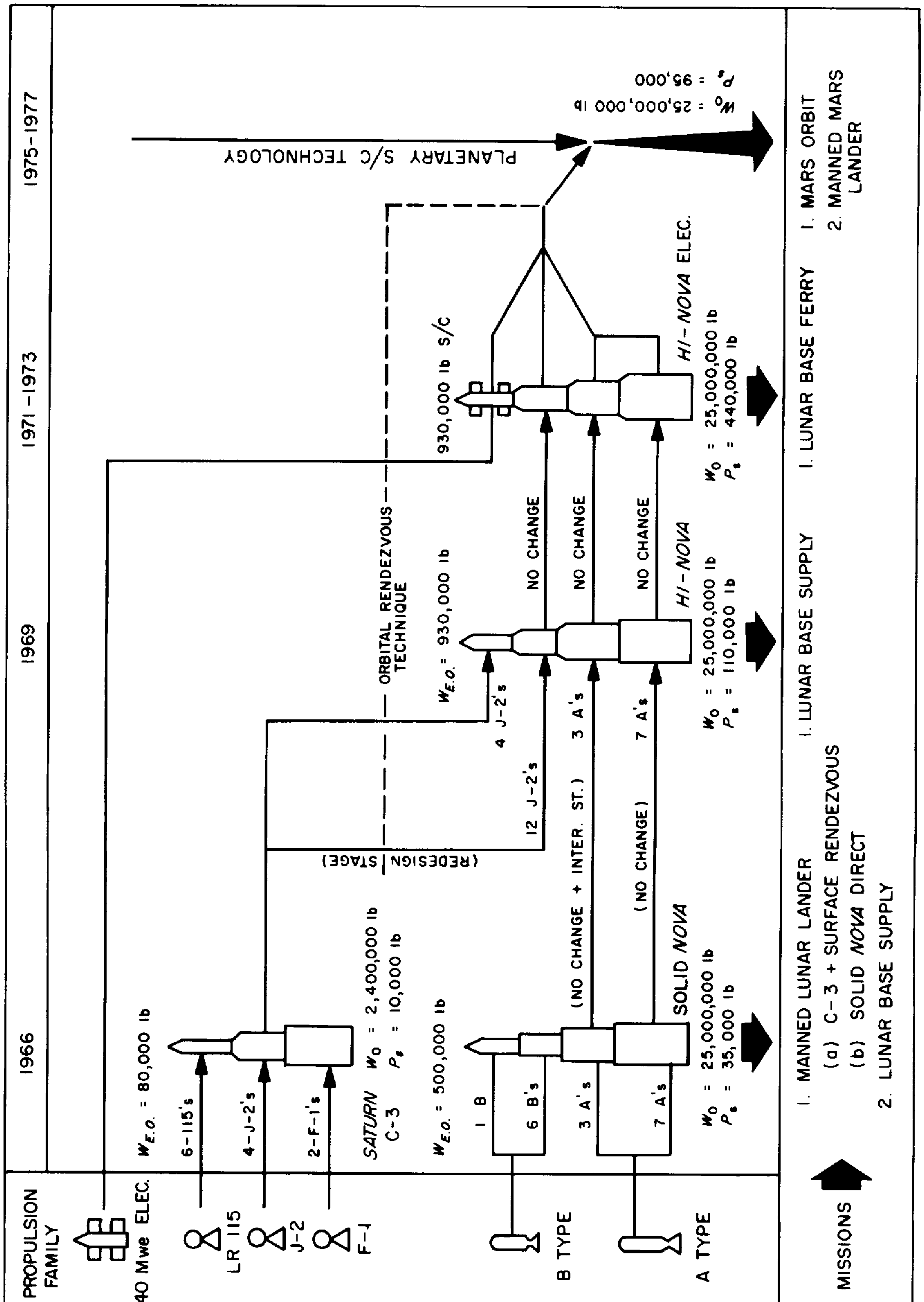

Fig. 2. Large launch vehicle family

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Figure 3 estimates the weight required in Earth orbit as a function of total round trip time for a 3-man Mars landing and return when the spacecraft is powered by (1) Lox-H_2 chemical, (2) *Rover*-type nuclear, and (3) electric propulsion. Calculations for the chemical and nuclear systems were based on Dugan's work (Ref. 3) and include indirect trajectories for the high-energy short-transit-time missions. Calculations for the electric systems were based on Moeckel's work (Ref. 4). The weight shown is that necessary in Earth orbit for 3 men to depart for a Mars orbit, split off a 3-man entry capsule with its Mars launch propulsion system, land on Mars, perform the necessary operations, take off and rendezvous with the orbiting spacecraft, and then return in the latter such that the 3-man Earth mission module of 15,000 lb reaches our atmosphere with parabolic velocity. All planetary calculations assume a fixed 50,000 lb of radiation shielding for the 3 men, approximately the average of the numbers discussed in the literature.

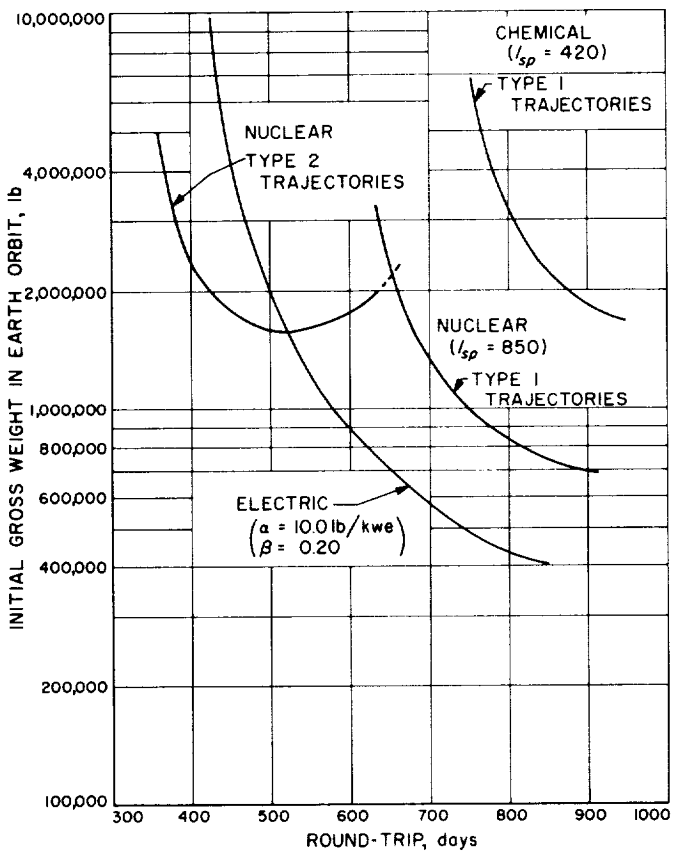

Fig. 3. Initial weight in Earth orbit vs Mars round-trip time

The required weights in Earth orbit are quite formidable. Indeed, the manned planetary program is one of the principal incentives and a major justification for developing a *Nova*-class vehicle. Obviously it is most desirable that much of this Mars vehicle capability should grow out of the lunar capability in order to save both time and money. The vehicle and spacecraft plan of Fig. 1 is an attempt to meet that requirement.

In Fig. 1 it is interesting to note that the *Nova* vehicle weight at launch remains the same, 25,000,000 lb, for all missions discussed. The two largest *Nova* stages remain essentially unaltered from 1961 to some period beyond 1975.

Table 1. Mars circumnavigation and orbiting missions

Type of mission	Initial weight required in 300 n.m. Earth orbit, lb	Round-trip time, days
Circumnavigation*	440,000	1,000
Orbit and Return	1,500,000	900

*Based on a single impulse trajectory

III. BASIS FOR THE PLAN

In the embryonic stage of the planning described here it was assumed that the four principal approaches for performing the manned lunar landing,

1. *Saturn* with orbital rendezvous,
2. *Saturn* with lunar surface rendezvous,
3. The liquid-propellant *Nova* and
4. The all-solid-propellant *Nova*,

would all be capable of performing the mission, though not necessarily on the same time schedule. The unpredictable delays in schedules would probably preclude, however, anyone's definitely showing that one method would be markedly shorter than the others and despite its importance, a choice would be difficult to make on this basis alone. Costs do appear to differ and will, in all probability, influence the final choice significantly.

As the plan developed and subsequent program requirements were recognized, the relative merits of single, dual, and triple approaches as a means of insuring mission success at the earliest date were examined briefly. Some qualitative conclusions resulted and influenced the plan accordingly.

A. Single Approaches for the Manned Lunar Landing

In the case of any one of the four above when used as a single approach, a delay in the vehicle or spacecraft schedule automatically would mean a corresponding delay in accomplishing the mission itself. In addition:

1. The *Saturn* with either the Earth orbit rendezvous or lunar surface rendezvous technique would provide inadequate follow-on capability, especially for the later planetary missions,
2. Either the liquid *Nova* or solid *Nova*, if developed alone and without the *Saturn* vehicle, would leave a rather serious gap in the performance capability of NASA's family of vehicles, i.e., no capability between the C-1 with 20,000-lb-orbit capability and the *Nova's* 300,000-to-500,000-lb capability, and
3. The liquid *Nova* alone would have less growth potential than the solid *Nova* unless a new, larger engine than the F-1 were developed or a rendezvous technique were utilized.

B. Dual Approaches

A dual approach would in general tend to enhance the chances of success at any given, early date. This would be especially true if independent approaches were adopted and different technical disciplines (e.g., liquid and solid propulsion) were involved such that the required competent technical personnel would not be spread too thin.

If the dual approach were:

1. The *Saturn* with orbital rendezvous and *Saturn* with lunar rendezvous, then the advantage of an independent approach would be lost; furthermore, follow-on capability would be inadequate.
2. Both the all-solid *Nova* and liquid *Nova*, then the program cost would be prohibitive; the approaches again would not be independent in that both depend on a major advance in the state-of-the-art in scaling-up size.
3. An all-solid *Nova* with a liquid C-3 rendezvous or the liquid *Nova* and a solid C-3 rendezvous, then the approaches would be completely independent. The former combination has greater growth potential for follow-on capability, however. Note, too, that the solid *Nova*, as indicated in TM 33-52, can probably be developed somewhat faster and considerably cheaper than the liquid *Nova*. Provided the *Saturn* C-3 were liquid, the existing F-1 and J-2 engine programs would be retained and we would continue to advance our large liquid propulsion and liquid hydrogen technologies.

A Hybrid *Nova* vehicle composed of solid lower stages and cryogenic liquid upper stages was considered and rejected as undesirable for the urgent manned lunar landing program. The advantage of a quick development schedule, characterized by the all-solid vehicle, would then be lost (1) because the advantages of dynamic scaling techniques would be diminished and (2) because of the pacing liquid-test-stand construction schedule.[2] Furthermore a completely independent mission approach is impossible when both vehicles of a parallel program have common subsystems; therefore, a Hybrid *Nova*, which contains both solid and liquid propellant stages would not permit an independent approach when it was associated with either a solid or a liquid C-3.

C. Triple Approaches

If a triple approach were adopted, such as the two *Nova* systems plus a C-3 lunar rendezvous, the likelihood of early success would probably be diminished rather than enhanced. The program would be so costly that public and congressional support would be difficult to maintain; reductions in funding might well mean all three would suffer. Such a huge effort would probably also imply a dilution of our competent technical personnel and complicate the management task to the point where mission success would be jeopardized.

Thus it was that the all-solid *Nova* and the liquid C-3 rendezvous were adopted as a concept warranting further consideration. Such a dual approach was believed to be consistent with the basic assumption of the report, that NASA must safely return men from the Moon as quickly as possible. In meeting these requirements, however, NASA should be preparing for subsequent milestones and building the "larger booster" competence that would be required at a later date. Fortunately, as outlined in Section II, the dual approach provides this required capability and with a minimum of duplication.

[2]Studies on a Saturn C-4 vehicle by General Dynamics ASTRONAUTICS indicate: "The major tests that are required for this vehicle in the preflight tests of the Development Program are necessary for each stage of the vehicle. For liquid-propellant stages, the engines undergo a series of basic development tests much in the manner of those conducted by a vehicle contractor. These engine tests culminate in a machine that can be employed in any of several designs of a vehicle. When the design of the vehicle is established, several series of preflight tests must be conducted to obtain preflight performance data and to assure adequate reliability and compatibility of the engine in its new design environment of the airframe. This is not so for the solid-propellant type engines. Since the solid-propellant case is usually the airframe, the vehicle contractor's task (and therefore time and cost) is greatly reduced. The design of a solid-propellant stage is sufficiently simple, in general, that few preflight tests are needed in the field by the vehicle contractor. The engine development and preflight captive tests are therefore one and the same for solid-propellant stages. Whatever tests are required on the part of the vehicle contractor are incorporated and conducted by the engine manufacturer at his facilities. By so doing, about two and one-half years could be saved (two years otherwise spent for captive test stand construction plus an additional six months before flight of captive testing) in this area alone by employing a solid-propellant stage, but this is useful only if all other stages employed solid-propellant."

D. Large Vehicle Family

One other constraint was also imposed early in the study. Any new vehicles that must be developed should fit logically into the NASA family of vehicles. It was deemed essential that the number of vehicle types developed and used be kept to a minimum in order thus to reduce their unit production cost and increase their reliability. Table 2 indicates the payload capability in Earth orbit and some estimated development and production costs of NASA's large vehicle family.

Table 2. Vehicle capabilities and costs

Vehicle	Payload lb	Development Cost $	Production cost for 20 vehicles, $/vehicle
Centaur	9,000	250,000,000*	9,000,000
Saturn C-3	80,000	1,800,000,000	25,000,000
Solid *Nova*	500,000	1,500,000,000	45,000,000
Hi-*Nova*	930,000	1,000,000,000	75,000,000

*Minus *Atlas* development

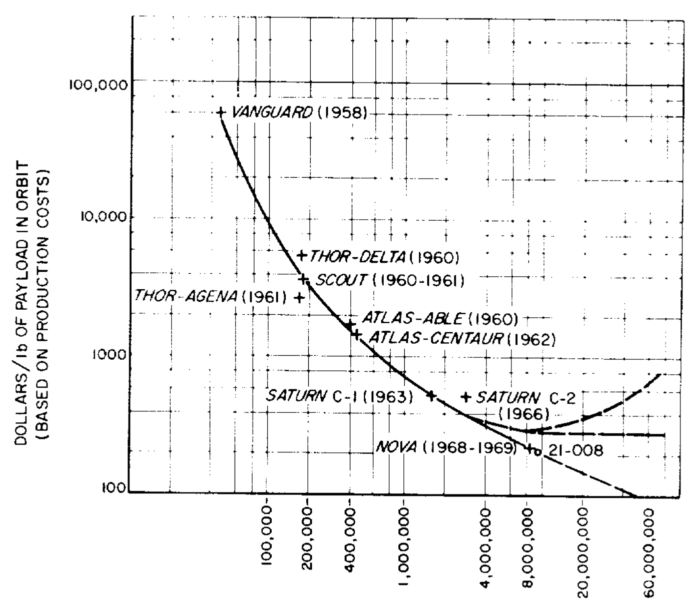

Fig. 4. System analysis: cost effectiveness

It may be noted that the development cost of a new large vehicle is so high that use of an existing vehicle with a large excess payload capability is preferable to the development of a new vehicle with an intermediate capability that matches the mission requirements; this is especially true when complete flight programs involve very limited numbers of vehicles. The above family of vehicles provides the wide range of payload capabilities desirable for the nation's manned missions; overlapping capabilities are avoided.

E. Unit Payload Cost Versus Vehicle Size

The requirements of the planetary missions for very large payload capabilities would seem to justify fully the development of a *Nova*-class launch vehicle. One might reasonably ask, however, whether smaller vehicles used in abundance with a rendezvous technique might prove to be more desirable economically. Recent studies by Space Technology Laboratories for Marshall Space Flight Center (Ref. 5) indicate that the unit payload cost continues to decrease however, as vehicle size increases from the *Saturn* class to the *Nova* class (see Fig. 4, taken from Ref. 5). Their studies also indicate (page 96 of Ref. 5) an all-solid *Nova* vehicle is competitive in production cost with the liquid *Nova* of the same payload capability. Cost studies in TM 33-52 tend to corroborate these conclusions. Thus it appears that there is also an economic incentive for NASA to develop a *Nova* vehicle provided it is used for an extensive number of flights and is not supplanted too quickly.

IV. IMPLICATIONS OF THE PLAN

Obviously, limited time for study has prevented examination of many important technological areas in depth, especially lunar spacecraft technology for the *Nova* injection vehicle, the manned planetary program, and the extensive development program for an advanced propulsion system. Nevertheless some general conclusions can be drawn from the short survey study discussed in this Addendum.

A. Disadvantages

1. The parallel approach for the manned lunar landing milestone in 1966 is somewhat more expensive than a single solid *Nova* or C-3 rendezvous approach[3] because two spacecraft must be developed; it must be recalled, however, that the spacecraft section that takes off from the lunar surface and re-enters our atmosphere is common to the two and would not require separate developments.
2. The use of twelve J-2 engines as the 3rd stage of the Hi-*Nova* vehicle may introduce a reliability problem. A more desirable arrangement might consist of a single Lox-H_2 engine in the F-1 class; this would require a new, large engine development.
3. The all-solid *Nova* will not provide a demonstration static firing of either the A or the B type of motor for approximately 3 years. For personnel who have had little experience with solid-propellant rocketry and who would have prime responsibility, this represents a long and agonizing period, a genuine act of faith for such an expensive and important program.

On the other hand there are some significant advantages also.

B. Advantages

1. The dual effort for the 1966 milestone constitutes an independent approach and gives added assurance of a successful and early lunar landing. Most of the dual effort, however, is not duplicated effort; both the C-3 and *Nova* vehicles are needed ultimately.
2. By capitalizing on propulsion features of the two programs a significant increase in capability is provided such that the two subsequent milestones, a lunar base and a manned Mars landing, can be performed in the shortest feasible time and with a minimum of vehicle development.
3. Work to advance our liquid hydrogen technology would proceed by way of the LR115 and J-2 engine programs.
4. Commitments on the F-1 and J-2 engines will continue and the engines will be utilized in the *Saturn* C-3 program. Adoption of a *Nova* based on solid propellants would, however, avoid commitment to, and complete dependence on, Lox-H_2 engines in all NASA vehicles, a commitment that must be made prior to the first successful flight demonstration of the latter type engine. One must consider very seriously the consequences of such a commitment if a delay in the *Centaur*, *Saturn*, and *Nova* vehicle schedules were to a arise for one and the same reason, an unpredictable problem in our liquid hydrogen technology.
5. The two vehicles considered in this Addendum, the liquid C-3 and the solid *Nova*, contribute to a balanced family of NASA vehicles which span the necessary range of payload requirements with a minimum number of vehicles and minimum overlap in capabilities.

In reviewing the program, several implications which are not necessarily obvious are worth noting also:

1. A parallel (all-liquid and all-solid) *Nova* approach would be prohibitively expensive; it would appear most desirable to choose one and drop the other within 3 to 6 months before heavy commitments for facilities are made. The choice becomes increasingly difficult as more funds are committed and vested interests become progressively stronger. Both systems will probably work ultimately; therefore, one of the two is unnecessary.
2. If the plan under review were adopted payloads of approximately 900,000 lb can be delivered into Earth orbit during the period 1967-69 without developing another much larger engine than that planned for the solid *Nova*. This probably implies that the development of very large chemical launch vehicles for NASA should be essentially complete at that time.

[3] However, the over-all injection vehicle costs for the solid *Nova* and C-3 parallel approach appear to be less than those of the liquid *Nova* injection vehicle alone.

In general further chemical launch vehicle development costs will not be justified by the improvements associated with those developments.

3. The capability of the vehicles suggested in the plan is sufficient to deliver part or all of a space station into Earth orbit. Our present weight limitation would have disappeared and the national space program could capitalize on new and unpredictable technological advancements. If a cost analysis shows that a nuclear third step is economically desirable and if it were to become available, the Hybrid *Nova's* payload in Earth orbit could be increased to approximately 1,500,000 lb.

4. If larger payloads than that of the Hi-*Nova*-electric are needed for the manned Mars landing, rendezvous in Earth orbit could be utilized; it is highly probable that no one component of the spacecraft will weigh more than 930,000 lb.

5. It is highly improbable that the manned Mars landing will be performed using chemical propulsion for the spacecraft for transit from Earth to Mars orbit; electric and nuclear propulsion appear to be much more practical for manned missions. Efforts in advanced propulsion must be accelerated and expanded soon if our manned planetary program is to be advanced expeditiously.

[redacted]

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